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HEATED SUB-FREEZING AIRFLOW DIVERTER

GOVERNMENT RIGHTS

[001] This invention was made with Government support under Contract Number M4225 awarded by Lockheed Martin Aerospace. The Government has certain rights in this invention.

BACKGROUND OF THE INVENTION

[002] The present invention generally relates to providing a uniform distribution of airflow to a heat exchanger and, more specifically, to apparatus and methods to improve the distribution of a high velocity (i.e., greater than or equal to about 250 ft/sec) sub-freezing (i.e., less than or equal to the freezing point of water, less than or equal to about 32°F) airflow provided to an inlet face of a heat exchanger.

[003] In many applications, environmental control systems that provide cooling to various heat loads, may operate utilizing expanding fluids flowing from an outlet of a turbine. Such airflows generally have high velocities of greater than or equal to about 250 ft/sec., and may be at sub-freezing temperatures less than about 32°F, typically as cold as about –30°F. Such airflows may not be evenly distributed upon entering a heat exchanger due to the small area of the turbine exhaust compared to the flow area of the heat exchanger inlet face. For example, such airflows may contain ice or snow created through the expansion cooling of air through the turbine, which can accumulate on, and may block portions of a heat exchanger inlet face that is immediately downstream. The airflow may also be stratified (e.g., non uniformly

distributed), thus being preferentially directed to a portion of the inlet face of the heat exchanger.

[004] Accordingly, non-uniform distribution of a high velocity, sub-freezing fluid flow may prevent the heat exchanger from operating in a most efficient manner. For example, the inlet face of the heat exchanger may become blocked by snow or ice formed as the compressed fluid (e.g., air) flows through the sudden expansion at the heat exchanger inlet pan to the inlet face of the heat exchanger. This blockage may require various components of the system to be larger than would be required without the blocking of the heat exchanger face, and/or may require anti-icing measures to be deployed, all of which may reduce the system effectiveness. This problem may exist in fluid conditioning apparatus and systems utilized in, for example, aircraft refrigeration systems such as those that provide environmental controls including cooling to various liquid and other heat loads generated by various components and systems in the aircraft.

[005] In an effort to address the above problems associated with non-uniform distribution of an expansion cooled fluid (e.g., an air flow) to a heat exchanger, such as those that may result from the blockage of the face of a heat exchanger located downstream of a turbine by ice or snow created through the expansion cooling of air through the turbine, systems directed to removal of water from the airflow prior to expansion through the turbine have been used. In one design shown in U.S. Patent no. 4,246,963, a condenser and water collecting means may be employed prior to the airflow entering the turbine to remove entrained liquid water from the airflow. Unfortunately, a water condenser may add an additional heat load onto the cooling system, and the condenser and water collection means may add additional weight and complexity to an aircraft or other environment in which this system may be located. An anti-ice bypass of bleed air may also be mixed with the cooler expanding air flowing from the turbine outlet to maintain the expanding air above freezing before entering the heat exchanger. However, this approach

may result in an energy drain on the overall system which may reduce system performance. Also, neither removal of water and/or the use of bypass air directly address stratification of the expanding airflow that may occur as it contacts the inlet face of the heat exchanger.

[006] Another approach directed to providing uniform distribution of a high velocity, sub-freezing airflow emanating from a turbine to the inlet face of a heat exchanger includes minimizing flow velocity stratification. In one design shown in U.S. Patent nos. 5,025,642 and 5,214,935, a back-pressure plate is utilized after the heat exchanger to block a portion of the outlet of the heat exchanger, thus causing the airflow to be more uniformly distributed through the heat exchanger. This approach may be used in conjunction with removal of the water vapor in the airflow prior to expansion of the airflow in the turbine. However, the backpressure created from this approach may adversely affect the efficiency of the system by increasing pressure drop, and the plate and other apparatus may add weight and complexity to the aircraft or other vehicle in which the system may be operating.

[007] Another approach directed to providing uniform distribution of a high velocity, sub-freezing airflow to the face of a heat exchanger includes the use of hollow tubes for header bars disposed directly on the face of, and in physical contact with, the heat exchanger. These tubes may be maintained above freezing (i.e., above about 32°F) and thus may prevent formation of ice thereon. In one design shown in U.S. Patent no. 4,246,963, elongated rounded surface hollow header bars traverse the cold air inlet of the heat exchanger to minimize ice formation thereon. However, these header bars do not impact stratification of the air flowing from the turbine outlet prior to the airflow entering the heat exchanger inlet face.

[008] As can be seen, there is a need for an apparatus and method that improves the uniformity of a high velocity, sub-freezing fluid flowing from a turbine outlet, as the airflow contacts the inlet face of a heat exchanger. The need extends to preventing blockage of the heat exchanger face by ice and

snow, to minimize stratification of the airflow and ice entering the heat exchanger, and to allowing the systems to operate at optimum efficiencies without the addition of systems, energy demands, and weight detrimental to overall performance.

SUMMARY OF THE INVENTION

[009] In one aspect of the present invention, a flow diverter comprises a heat sink array in fluid communication near an inlet face of a heat exchanger, the heat sink array comprising a plurality of heat sink elements, the heat sink array being separated from the inlet face by a distance, and the heat sink array being positioned between the turbine outlet and the inlet face such that at least a portion of a fluid flowing from the turbine outlet contacts the heat sink array before the portion of the fluid contacts the inlet face of the heat exchanger.

[010] In another aspect of the present invention, a flow diverter comprises a heat sink array in fluid communication between a turbine outlet and an inlet face of a heat exchanger, the inlet face being in fluid communication with an outlet face of the heat exchanger, the heat sink array comprising a plurality of heat sink elements, the heat sink array being separated from the heat exchanger inlet face by a distance, and the heat sink array being positioned between the turbine outlet and the heat exchanger inlet face such that at least a portion of a fluid flowing from the turbine outlet contacts the heat sink array before the portion of the fluid contacts the heat exchanger inlet face to provide a uniform temperature distribution of the fluid across the outlet face.

[011] In still another aspect of the present invention, a fluid flow diverter comprises a heat sink array in fluid communication between a turbine outlet and an inlet face of a heat exchanger, the heat sink array being separated from the inlet face by a first distance, the heat sink array being positioned between the turbine outlet and the inlet face such that at least a portion of a fluid flowing from the turbine outlet contacts the heat sink array before the portion of the fluid

contacts the heat exchanger inlet face, the heat sink array comprising a plurality of hollow tubes, the plurality of hollow tubes being arranged essentially perpendicular to the fluid flowing from the turbine outlet, the plurality of hollow tubes characterized by an essentially circular cross section, the plurality of hollow tubes having an outer surface separated from an inner surface by a wall thickness, and the inner surface being in fluid communication with a heat exchange medium, wherein the outer surface of at least one of the hollow tubes is located a second distance of about 5% to about 50% of a third distance between the turbine outlet and the heat exchanger inlet face.

[012] In yet another aspect of the present invention, a cooling air system ~~comprises,~~ comprises a turbine having a turbine outlet in fluid communication with an inlet face of a heat exchanger, the inlet face being in thermal and fluid contact with an outlet face of the heat exchanger, the inlet face being disposed between the turbine outlet and the outlet face of the heat exchanger, a heat sink array positioned between the turbine outlet and the heat exchanger inlet face such that at least a portion of a fluid flowing from the turbine outlet contacts the heat sink array before the fluid contacts the heat exchanger inlet face, the heat sink array being separated from the heat exchanger inlet face by a distance, the heat sink array comprising a plurality of hollow tubes, the plurality of hollow tubes having an outer surface separated from an inner surface by a wall thickness, the inner surface being in fluid communication with a heat exchange medium, the plurality of hollow tubes arranged to the fluid flowing from the turbine outlet to provide a uniform temperature airflow, and water flow distribution of the fluid across the heat exchanger outlet face.

[013] In yet another aspect of the present invention, a fluid flow diverter comprises an expansion chamber or pan having a turbine outlet at a first end and a heat exchanger inlet face at a second end located opposite to, and in fluid communication with the first end, a heat sink array comprising a plurality of heat sink elements disposed within the expansion chamber between, and in fluid communication with the first end and the second end, wherein a portion of a

fluid entering the first end contacts the heat sink array prior to the fluid contacting the second end, and wherein the heat sink array is positioned a distance from the second end.

[014] In still another aspect of the present invention, a method of distributing a fluid to a heat exchanger comprises expanding the fluid through a turbine having a turbine outlet in fluid communication with an inlet face of the heat exchanger, diffusing the fluid through the turbine outlet diffuser, contacting a portion of the fluid with a flow diverter arranged between the turbine outlet and the heat exchanger inlet face, the flow diverter comprising a heat sink array, the heat sink array being separated from the heat exchanger inlet face by a distance, and the heat sink array being positioned between the turbine outlet and the heat exchanger inlet face such that at least a portion of the fluid flowing from the turbine outlet contacts the heat sink array before the portion of the fluid contacts the inlet face.

[015] These and other features, aspects and advantages of the present invention will become better understood with reference to the following drawings, description and claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[016] Figure 1 is a schematic representation of a cooling air system embodying the principles of the present invention;

[017] Figure 2 is an enlarged view showing detail A of Figure 1;

[018] Figure 3 is a perspective view of an embodiment of the present invention showing a heat sink array disposed within an expansion chamber or pan in front of a heat exchanger;

[019] Figure 4 is a view in the direction of the fluid flow out of the turbine showing an embodiment of the present invention having a heat sink array with a staggered arrangement of elements;

[020] Figure 5 is a view of a heat exchanger outlet face with temperature

measurement locations;

[021] Figures 6a – 6g are longitudinal, cross sectional views of various embodiments of heat sink elements according to the present invention;

[022] Figure 7a is a graphical representation of temperatures measured across an outlet face of a heat exchanger according to an example of the present invention; and

[023] Figure 7b is a graphical representation of temperatures measured across an outlet face of a heat exchanger according to an example of the prior art.

DETAILED DESCRIPTION OF THE INVENTION

[024] The following detailed description is of the best currently contemplated modes of carrying out the invention. The description is not to be taken in a limiting sense, but is made merely for the purpose of illustrating the general principles of the invention, since the scope of the invention is best defined by the appended claims.

[025] The present invention generally provides a cooling air system comprising a turbo compressor, which may have an outlet that may be in fluid communication with a heat exchanger. In the cooling air system of the present invention, a fluid such as air may be compressed in the compressor. A compressed fluid may then be directed towards the regenerative heat exchanger which may be cooled by exhaust air from an expansion turbine. The cooling air system may be utilized aboard a vehicle, for example aboard an aircraft. Accordingly, the cooling air system may be, for example, an open loop cooling air system. The cooling provided for by the system may be used to cool various heat loads, such as those onboard a vehicle in which the system is located. The cooling air system of the present invention generally provides a flow diverter that may include a heat sink array arranged between an outlet of a turbine, and an inlet face of a heat exchanger, such as those that may be

utilized, for example in an open or closed loop aircraft cooling air system. The heat sink array may thus be positioned between the turbine outlet and the inlet face of the heat exchanger such that at least a portion of a fluid flowing from the turbine outlet contacts the heat sink array before the portion of air contacts the inlet face of the heat exchanger. The heat sink array may be spaced away (i.e., positioned a distance away) from the inlet face of the heat exchanger, thus the heat sink array of the present invention may not be in physical contact with the inlet face of the heat exchanger. This is unlike the prior art of cooling air systems, wherein elongated rounded surface hollow header bars that traverse the cold air inlet of the heat exchanger are an integral part of the heat exchanger itself.

[026] In the present invention, an expansion cooled fluid flowing from the turbine outlet may have a high velocity (i.e., a velocity greater than about 250 ft/sec) and the expanding fluid may have a temperature of less than the freezing point of water, about 32°F, with temperatures of less than about –50°F being possible. The expanding fluid may also contain water, which may be in the form of ice crystals or snow. The heat sink array of the present invention may be maintained at a temperature above the freezing point of water (i.e., a temperature above about 32°F) while the heat sink array is in contact with the fluid, which may prevent ice crystals from blocking the inlet face. This too is unlike the prior art of cooling systems, wherein water may be removed from the air prior to the air being compressed.

[027] The flow diverter of the present invention may be positioned such that at least a portion of the fluid flowing from the turbine outlet contacts the heat sink array before the portion contacts the inlet face such that a uniform temperature distribution of the fluid may be provided across the entire outlet face of the heat exchanger. This too is unlike the prior art of cooling air systems, which may block a portion of the outlet of the heat exchanger, where the heat exchanger core features a slot that allows cold side flow to bypass the core. The outlet blockage may cause the airflow to be more uniformly

distributed through the heat exchanger, but with an increase in backpressure and a decrease in overall heat exchanger and system performance.

[028] Referring now to the figures, and more particularly to Figure 1, an embodiment of the present invention that provides a cooling air system is shown generally at 10. An engine 12 may have its bleed air 14 pressure regulated with a bleed air valve 16. The resulting bleed air 14 airflow may undergo cooling in a primary heat exchanger 18 by the introduction of ram air 20. The bleed airflow may then undergo compression in a compressor 22, which may be cooled in a regenerative heat exchanger 79. A turbine 24 can receive the airflow from the regenerative heat exchanger 79. An expansion cooled airflow 26 flows from the turbine outlet 28.

[029] The expansion cooled airflow 26 emanating from the turbine outlet 28 may be at its coolest and can serve as a source for cooling radar electronics and other heat loads, represented generally as 30, via a liquid coolant circuit, represented generally as 32, which may in turn be cooled by expansion cooled airflow 26 via a liquid/air heat exchanger 42. The liquid coolant circuit 32 may include various liquid coolant valves 34, a liquid coolant pump 36, a liquid reservoir 38, coolant controls 40 and a coolant filter 41. The expansion cooled airflow 26 may also be utilized for forced-air cooling of avionics (not shown), and cooling of an aircraft cabin (not shown).

[030] The expansion cooled air 26 from the turbine outlet 28 may be in fluid communication with the liquid/air heat exchanger 42 through expansion chamber 48, also referred to as an inlet pan. A portion of the expanding airflow 26 may contact a heat sink array 50 and then contact an inlet face 52 of the heat exchanger 42, pass through the heat exchanger 42, and exit heat exchanger 42 through an outlet face 78 of the heat exchanger.

[031] As better seen in Figure 2, an embodiment of the present invention may comprise a heat sink array 50, which may be positioned between turbine outlet 28 and the inlet face 52 of heat exchanger 42 such that at least a portion of an expansion cooled fluid flow 26, which may flow from the turbine outlet 28,

contacts the heat sink array 50 before the portion of the fluid flow 44 after heat sink array 50 contacts the inlet face 52. The heat sink array 50 may comprise a plurality of heat sink elements 54. Heat from heat load 30 may be provided to heat sink array 50 from liquid cooling circuit 32 and such heat can be in an amount sufficient to maintain surface temperature of heat sink element 54 above the freezing point of water (which may vary depending on the operational conditions of the system, but which may generally be above about 32°F) while heat sink array 50 may be in contact with expansion cooled airflow 26. Heat from heat load 30 may also be provided to walls 46 of expansion chamber 48 via liquid cooling circuit 32 through a jacket 90 disposed within the walls of expansion chamber 48.

[032] In an embodiment, heat sink array 50 may be spaced away from inlet face 52 and/or from turbine outlet 28, such that heat sink elements 54 of heat sink array 50 may not be in physical contact with turbine outlet 28 or with inlet face 52 of heat exchanger 42. In an embodiment, a plurality of heat sink elements 54 of heat sink array 50 may be arranged in a plane 68 located a first distance 72 between turbine outlet 28 and heat sink array 50, which may be about 1% to about 99% of a second distance 74 located between the turbine outlet 28 and the inlet face 52 of heat exchanger 42. The first distance 72 may preferably be about 5% to about 75% of the second distance 74. In another embodiment, the first distance 72 may be about 10% to about 50% that of second distance 74.

[033] In an embodiment of the present invention, and as an example, the velocity of the expansion cooled airflow 26 flowing from the turbine outlet 28 may have a velocity greater than or equal to about 250 ft/sec. In a further embodiment, the temperature of the expanding airflow 26 flowing from the turbine outlet 28 may be less than about 32°F, with less than about –30°F in another embodiment, and less than about –50°F in yet another embodiment.

[034] In such above embodiments, the heat sink array 50 may be arranged within expansion cooled airflow 26 such that at least a portion of the airflow 26

may contact heat sink array 50 to produce an airflow 44 which may have a velocity reduced from that of airflow 26. As an example, the velocity of airflow 26 may be about 5 or more times greater that a velocity of airflow 44, which may be in contact with inlet face 52 (e.g., located within expansion chamber 48 after heat sink array 50). As another example, the velocity of airflow 26 located within expansion chamber 48 prior to heat sink array 50 may preferably be about 10 or more times the velocity of the airflow 44 in contact with inlet face 52. In still another example, the velocity of airflow 26 located within expansion chamber 48 prior to heat sink array 50 may be about 20 or more times the velocity of airflow 44 in contact with inlet face 52. The reduction in velocity provided by airflow 26 contacting heat sink array 50 provides for a uniform distribution of the airflow and entrained humidity 44 to the inlet face 52 of the heat exchanger. Accordingly, the reduction in the velocity of airflow 26 provided by contacting with heat sink array 50 may result in mixing and diffusion of the airflow 44 within the expansion chamber 48, which in turn may provide a uniform distribution of the airflow and entrained humidity 44 to the inlet face 52. The uniform distribution of the flow 44 to the inlet face 52 thus, may provide for a uniform temperature distribution of the airflow across the outlet face 78, as described in detail below. Referring to Figure 3, an embodiment of the present invention may include a heat sink array 50 comprising a plurality of heat sink elements 54, which may be arranged in a plurality of planes 68 and 70 within expansion chamber 48 in front of inlet face 52 of heat exchanger 42. In an embodiment, the heat sink array 50 may comprise a plurality of heat sink elements 54 arranged in a staggered configuration with respect to the direction 92 of airflow 26. A staggered configuration of heat sink elements may include a first portion 104 of heat sink elements 54 disposed in a first plane represented by dotted line 68, and a second portion 106 of heat sink elements 54, which may be disposed in a second plane 70. Planes 68 and 70 may each be at the same angle to direction 92 of airflow 26. Heat sink elements 54 may further be disposed in a plurality of planes (e.g., 94, 96, and 98), which may be essentially

parallel to the direction 92 of airflow 26. In an embodiment, heat sink elements 54 may be disposed in planes 68 and 70 which are essentially perpendicular to the direction 92 of expanding airflow 26 between the turbine outlet 28 and the inlet face 52 of heat exchanger 42.

[035] Figure 4 shows a perspective view of the embodiment shown in Figure 3, which shows an embodiment in the direction of the fluid flow from the turbine 92. Heat sink elements 54 may be arranged within the perpendicular plane 68 to the direction 92 of the airflow, and may be arranged essentially parallel to each other within planes 68 (obscured in Figure 4) and plane 70. Furthermore, in an embodiment, heat sink array 50 may comprise a plurality of heat sink elements 54, which may be characterized by a variety of shapes and arrangements described below.

[036] Referring to Figure 5, a view of an outlet face 78 of a heat exchanger 42 is shown looking into the direction of flow. In an embodiment, an essentially uniform temperature distribution of the airflow across the outlet face 78 of heat exchanger 42 may be characterized by a plurality of temperatures of the fluid 82 measured at the outlet face 78 of the heat exchanger 42 at a plurality of equal and adjacent intervals 86 spanning a line from a center point 80 of the outlet face 78 to an outer edge 88 of the outlet face 78. Accordingly, in an embodiment, the heat sink array 50 may be arranged to contact expansion cooled airflow 26 within the expansion chamber 48 (see Figure 2) to provide a uniform temperature of the fluid at the outlet face 78 such that the resulting temperature distribution has less-temperature variation from the center point 80 of the heat exchanger face to the outer edge 88. For example, each of five (5) temperatures 82, as an example, of the fluid measured at the outlet face 78 at five (5) equal and adjacent intervals 86 spanning a line from a center point 80 of the outlet face 78 to an outer edge 88 of the outlet face 78, have a total temperature variation of about 6°F. In another embodiment without the use of the flow diverter device, the resulting temperature distribution is more varied with a larger temperature variation of 9 °F from the center point 80 of the heat

exchanger to the outer edge 88.

[037] Various cross sectional views of embodiments of heat sink element 54 are shown in Figures 6a through 6g. In an embodiment shown in Figure 6a, heat sink element 54 may include a solid member in thermal contact with heat load 30 (not shown), for example via a heat exchange medium (not shown) provided by liquid cooling circuit 32 (not shown), having an outer surface 56 which may be in physical contact with expansion cooled airflow 26. In another embodiment shown in Figure 6b, heat sink element 54 may include an electric heater 58 disposed within heat sink element 54. In still another embodiment as shown in Figure 6c, heat sink element 54 may comprise a hollow member 60 having an outer surface 56 separated from an inner surface 62 by a wall thickness 64. The inner surface 62 may be in fluid communication with a heat load 30 (not shown), for example via a heat exchange medium (not shown) provided by liquid cooling circuit 32 (not shown) having a temperature greater than the freezing point of water. In an embodiment, hollow member 60 may be characterized by an essentially circular cross section (Figure 6c) and may have an outer diameter 66 greater than or equal to about 4 times wall thickness 64.

[038] Heat sink element 54 may also be characterized by a cross section comprising a plurality of straight sides, curved sides, or a combination thereof. For example, in embodiments shown in Figures 6d-6g, heat sink element 54 may include a hollow member 60 having an outer surface 56, and inner surface 62 and a cross section characterized by a triangular shape (Figure 6d), a diamond shape (Figure 6e), an oval shape (Figure 6f), and/or a tear-drop, aerodynamic shape (Figure 6g).

[039] Referring to Figures 1-6, a method of distributing a fluid such as an expansion cooled airflow 26 to a heat exchanger 42 may include expanding a fluid (e.g., air) through a turbine 24 or other type of device having an outlet 28 in fluid communication, through an expansion chamber 48, with an inlet face 52 of a heat exchanger 42. The method may further comprise contacting at least a portion of the expansion cooled airflow 26 with a heat sink array 50 prior to that

portion of the airflow contacting the inlet face 52 of heat exchanger 42. In an embodiment, the heat sink array 50 is positioned a distance from the inlet face 52, and may comprise a plurality of heat sink elements 54, which may be in thermal contact with a heat load such that heat sink elements 54 may be maintained at a temperature above the freezing point of water while in contact with the expansion cooled airflow 26. In another embodiment, the heat sink array 50 may comprise a plurality of hollow members 60, which may be positioned within the expansion cooled airflow 26 to contact at least a portion thereof, which may provide a more uniform mass flow and ice load on the inlet face 52 and result in a more uniform temperature distribution of the airflow across an outlet face 78 of the heat exchanger 42.

EXAMPLES

[040] A test stand designed to simulate an open loop aircraft cooling system similar to that shown in Figure 1 was utilized in testing the present invention. The test stand was outfitted with a turbine having a turbine outlet in fluid communication with an inlet face of a heat exchanger through an expansion chamber (i.e., an inlet pan). The testing conditions provided a flow of expanding air from the turbine outlet having a temperature of about –40°F at a velocity of about 250 ft/sec. A simulated heat load was supplied to the heat exchanger, and to the flow diverter of the present invention when applicable. In this example, the flow diverter comprised two rows of four tubes spanning across the inlet pan. The outlet face of the heat exchanger measured about 6 inches in height, and about 10 inches across, as measured from a left face of the heat exchanger. The center point of the heat exchanger was at a height of about 3 inches, and a distance from the left face of about 5 inches. During the test, a plurality of air temperatures were measured at a plurality of intervals equally distributed across the outlet face of the heat exchanger along a grid pattern centered on the line running through the center point of the heat

exchanger. The data are summarized in Table 1 below.

Table 1

Sample	Distance from Left Face In.	Height In.	Air Temperature °F
Example	4.5	3	105
	4.5	2.4	104
	4.5	1.8	102
	4.5	1.2	100
	4.5	0.6	99
Comparative Example	4.5	3	105
	4.5	2.4	104
	4.5	1.8	103
	4.5	1.2	99
	4.5	0.6	96

[041] Figures 7a shows a two dimensional representation of the air temperature distribution across an outlet face of a heat exchanger of the present invention, wherein a portion of a fluid flowing from a turbine outlet contacts a heat sink array as described above, located a distance away from a heat exchanger inlet, before the fluid contacts the inlet face of the heat exchanger.

[042] Figure 7b shows a two dimensional representation of the temperature distribution across the outlet face of the heat exchanger of the prior art. Comparative Example data was determined taken under essentially identical conditions as used to acquire the data shown in Figure 7a.

[043] As can be seen from Table 1 and the graphical representations of the data in Figures 7a and 7b, a uniform temperature distribution across the outlet face was obtained using the flow diverter of the present invention, as compared to the non-uniform temperature distribution obtained in the Comparative Example. This uniform distribution being characterized by regions having essentially the same temperature, which varying from 99 to 105°F across the outlet face such that each of a plurality of temperatures of the fluid measured at the outlet face of the heat exchanger at 5 equal and adjacent intervals have a total temperature difference of about 6 °F.

[044] A less uniform temperature distribution is seen in the Figure 7b, showing the temperatures measured across the outlet face of the heat exchanger used in the Comparative Example without the flow diverter described herein. As shown in Table 1 and in Figure 7b, the temperatures across the outlet face of the Comparative Example vary from 96 to 105°F across the outlet face, compared to 99 to 105°F for the Example.

[045] It should be understood, of course, that the foregoing relates to preferred embodiments of the invention and that modifications may be made without departing from the spirit and scope of the invention as set forth in the following claims.